Minerals Engineering 125 (2018) 94–110

Contents lists available at ScienceDirect

Minerals Engineering

journal homepage: www.elsevier.com/locate/mineng

Deconvolution of fractionation data to deduce consistent washability and partition curves for a mineral separator

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ARTICLE INFO

Keywords:
Density fractionation
Partition
Washability
Grade-recovery

ABSTRACT

A density partition curve for a hypothetical steady-state separator is applied to a known feed density distribution to give the density distributions of the product and reject. Density fractionation of each of these streams is then simulated, with the fractionator *Ecarte Probable*, Ep_X, set at a specific level, to produce a set of seven or more fractions of varying mass and increasing average density. This study then describes a new algorithm that attempts to recover the partition curve of the original steady-state separator, using only the three sets of limited fractionation data and the assumption that the form of the partition curve equation is known. The algorithm first uses a simple interpolation rule to convert each set of fractionation data into a cumulative density distribution. Then the feed density distribution and the partition curve parameters are simultaneously adjusted until a consistent set of feed, product and reject density distributions is found with minimum variation from the raw fractionation data. The algorithm was applied to a simple rectangular feed distribution, and then a more realistic distribution. In both cases the algorithm accurately determined the density cut point (D_{50}) of the separator, even for poor quality fractionations. The accuracy of the determined separator *Ep* value depended on the fractionator Ep_X and the amount of near-density material. For the simple rectangular distribution, the algorithm under predicted the separator *Ep*, with the error being about 34% of the fractionator Ep_X. For the more realistic feed distribution, there was more scatter in the *Ep* values, but still the same general trend. The error increased when there was little near-density material. Increasing the number of flow fractions from 7 to 11 brought some improvement in accuracy. However, above 11 fractions there was no further significant improvement. Expressing the partition function in terms of D_{75} and D_{25} (instead of D_{50} and *Ep*) reduced the sensitivity of the algorithm to the initial guess values.

1. Introduction

Accurate resource assessment, plant design, and process assessment require knowledge of the density distribution of mineral particles. This distribution varies with particle size due to mineral liberation. The traditional sink-float method has provided the necessary information in the coal industry, made possible by the availability of sufficiently dense liquids, although even here there are problems due to health and environmental concerns, and the costs of the liquids and their effects on the coking properties of the clean coal composites produced (Galvin, 2006; Iveson and Galvin, 2012). However, the situation is more extreme in the minerals industry which requires considerably denser liquids. Lithium tungstate solutions (LST), which are aqueous based, have provided a valuable reprieve, but their density range is limited to less than 3000 kg/m^3 at room temperature (and up to 3500 kg/m^3 at elevated temperatures), and costs are significant (Central Chemical Consulting, n.d). The highest liquid density offered by any of the Australian commercial laboratories contacted by the authors was 4400 kg/m^3, whereas in many cases it would be desirable to measure densities much higher than this.

Increasingly, mineral liberation analysis using advanced scanning electron microscopy is being used to quantify the density distribution. Well known systems include QEMSCAN, TIMA and MLA, supported by software for identifying and assigning densities and sizes to particles in the sample specimen. The information produced is inferred, with 2-D sectional views used to quantify the 3-D particle size (Burrows and Gu, 2006; CSIRO, 2016; TESCAN, 2017). More recently new 3D X-ray systems have been used to quantify in three-dimensions the particle geometry, equivalent size, and density to produce the particle washability (Miller and Lin, 2018). These approaches do not produce material separations that can be analysed directly. Nevertheless, the techniques are powerful and likely to be used in the absence of alternatives, especially for relatively fine particles.

The authors have been developing novel particle fractionation

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https://doi.org/10.1016/j.mineng.2018.05.010
Received 1 March 2018; Received in revised form 4 May 2018; Accepted 5 May 2018

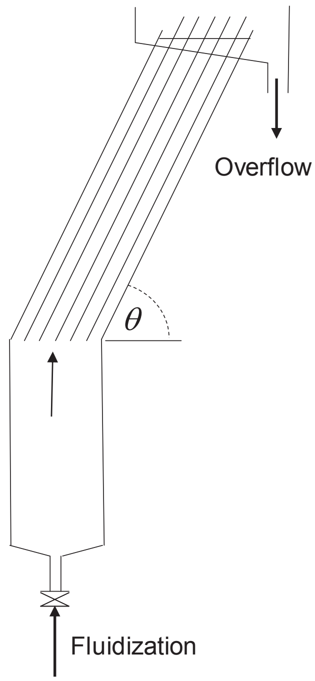

Fig. 1. Schematic diagram of the REFLUX™ Classifier, comprising of a vertical fluidization section and an inclined section of parallel plates. The semi-batch fractionation configuration is shown, in which there is no continuous feed solids addition or underflow removal. Fluidisation water is injected from the base at progressively higher flowrates to elutriate increments of solids from an initial batch.

methods utilizing the REFLUX™ Classifier, a fluidized bed device, with a system of parallel inclined channels above, as shown in Fig. 1. Galvin (2009) has described the general approach, developing an algorithm for correcting the data, achieving good agreement with the sink-float method for coal. The flow fractions produced in that work were governed by both the particle size and the density, hence from a density perspective, there was a degree of "mixing" between adjacent flow fractions. The algorithm performed the necessary "un-mixing", utilizing knowledge governing the underlying hydrodynamics. The algorithm, which was validated for coal and mineral matter feeds, was complex and hence difficult to apply.

Since then improvements in the fractionation produced by the REFLUX™ Classifier have been achieved in several ways. Galvin et al. (2009) discovered that closely spaced inclined channels promoted a laminar parabolic flow profile in which the velocity experienced by a particle resting on the wall became roughly proportional to its size, thus reducing the dependence of elutriation velocity on particle size. Using inclined channels with a spacing of 1.77 mm and length of 1000 mm, Galvin and Liu (2011) further discovered that high laminar shear rates induced an inertial lift force, which lifted the lowest density particles off the surface of the incline. The lower density particles thus joined the strong flow up through the inclined channels, reporting to the overflow. Very good agreement with the sink-float method was obtained for coal feeds in the size range 0.038–0.250 mm without the need for an algorithm to correct the data. For coarser particles, wider inclined channels were needed. To preserve the laminar flow condition in these wider channels, Hunter et al. (2014) used viscous aqueous glycerol solutions, typically 70 wt% concentration, as the fluidizing medium. Applied to coal, the elevated liquid density also amplified the effect of the shear induced inertial lift. Utilizing channels with a spacing of 6 mm this gave very good agreement with the sink-float method for particles in the size range from 0.250 to 2.00 mm. Indeed, the agreement was so strong, it was possible to produce the partition curve for a separator by applying the method to the feed, product, and reject streams (Iveson et al., 2015). The technique was also extended to particles in the size range 2.0–16.0 mm, using wider channels, achieving satisfactory results.

The application of the REFLUX™ Classifier to beneficiate feed samples containing dense minerals, notably fine iron ore less than 1 mm, has also recently been investigated. Here, the buoyant particle weight force in a medium of water is significant, even for the lower density gangue species such as silica. Thus, an inertial lift force that was sufficient to lift a particle of coal in water, is no-longer sufficient to cause lift, at least under the dilute conditions of the semi-batch system. With higher flow rates, and narrower channel spacing, particle lift can still be generated. However, due to the need to promote a laminar flow profile within the inclined channels, a 70 wt% glycerol solution was again used, meaning the required flow rates and hence shear rates were reduced. Thus, unlike for coal, the fractionation performance for dense minerals became compromised (Hunter et al., 2017).

Attention has since returned to developing a suitable algorithm for processing any density-based fractionation data. The data of the form shown in Table 1 are generated using samples of the feed, product, and reject collected from a gravity separator operated at steady state. The mass and average density of material in a number of fractions of progressively increasing average density are measured, however there is an unknown amount of overlap in the density range between each fraction. The challenge is to determine the true density distribution of each stream, in other words the washability data of each stream, and the fundamental link between the feed, product, and reject, expressed in terms of a partition curve.

The usual approach to obtaining a partition curve involves independently measuring the density distribution of each flow stream, using common density ranges for each stream. Whilst it is theoretically possible to infer partition results from measurements of only two of the three streams, it is generally recommended that all three streams are sampled, which then requires the assistance of mass balance reconciliation to generate a consistent set of data. Once the density

Table 1
Sample feed, product and reject batch fractionation data. Normally only the mass and average density of material in each fraction are known. This data was simulated using the method described in Section 2.2 based on Feed 2 treated in a separator with $D_{50,T}$ = 3500 kg/m^3 and Ep_T = 300 kg/m^3.

	FEED (F)			PRODUCT (P)			REJECT (R)		
Fraction (–)	$D_{50,X}$ (kg/m^3)	Mass (g)	Density (kg/m^3)	$D_{50,X}$ (kg/m^3)	Mass (g)	Density (kg/m^3)	$D_{50,X}$ (kg/m^3)	Mass (g)	Density (kg/m^3)
1	2800	7.66	2917	3100	2.84	3126	2700	4.64	2884
2	3100	12.28	3038	3400	3.72	3327	2800	4.82	2933
3	3500	13.26	3254	3900	4.93	3673	2900	4.53	2998
4	4000	8.29	3646	4400	8.88	4485	3100	5.35	3094
5	4400	8.71	4498	4600	12.35	4723	3300	4.63	3210
6	4800	23.13	4765	4800	16.15	4813	3500	3.01	3345
Remains		26.66	4862		21.21	4874		2.93	3734
Sum		100.0			70.1			29.9	
Average			3954			4472			3109.7